

Multiple Scattering, Parton Energy Loss and Modified Fragmentation Functions in Deeply Inelastic eA Scattering *

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The propagation of an energetic parton and its induced energy loss has been proposed as a probe of the properties of dense matter formed in high-energy nuclear collisions. Recent theoretical studies show that a fast parton will lose a significant amount of energy via induced radiation when it propagates through a hot partonic matter. One cannot directly measure the energy loss of partons because they are not final experimentally observed particles. However, parton energy loss does lead to modification of the final particle spectra. Therefore, one can only study the parton energy loss indirectly by measuring the modification of the parton fragmentation functions in semi-inclusive processes like eA or γ -jet events in AA collisions or the inclusive spectra at large transverse momentum.

In this Letter, we report our first study and derivation of the QCD evolution equations for the medium-modified fragmentation functions in the simplest case of deeply inelastic eA scattering (DIS). The induced gluon radiation due to multiple parton scattering gives rise to additional terms in the modified QCD evolution equations that soften the modified fragmentation functions. Utilizing the generalized factorization of higher-twist (HT) parton distributions, we show that these additional HT terms depend on both the diagonal and off-diagonal twist-four parton distributions, the combination of which clearly manifests the Landau-Migdal-Pomeranchuk (LPM) interference pattern. Using estimates of these twist-four parton matrix elements from other processes such as the p_T broadening of Drell-Yan dilepton in pA collisions, we predict the modification of the effective quark fragmentation functions and their dependence on the parton energy and nuclear size. We also estimate the quark energy loss defined as the total energy carried by gluons from induced radiation.

Summing up all the leading contributions from LT and HT processes, we can effectively define

the modified quark fragmentation function as

$$\frac{dW_{\mu\nu}}{dz_h} = \sum_q e_q^2 \int dx f_q^A(x, \mu_I^2) H_{\mu\nu}^{(0)}(x, p, q) \times \tilde{D}_{q \rightarrow h}(z_h, \mu^2). \quad (1)$$

where for completeness $f_q^A(x, \mu_I^2)$ should also include the HT contributions as studied by Mueller and Qiu. The modified quark fragmentation function satisfies the following evolution equation

$$\begin{aligned} \frac{\partial \tilde{D}_q(z_h, \mu^2)}{\partial \ln \mu^2} &= \frac{\alpha_s}{2\pi} \int_{z_h}^1 \frac{dz}{z} \left[\tilde{\gamma}_{q \rightarrow qg}(z, x, x_L, \mu^2) \right. \\ &\times \tilde{D}_q(z_h/z, \mu^2) \\ &+ \tilde{\gamma}_{q \rightarrow qg}(1-z, x, x_L, \mu^2) \\ &\times D_g(z_h/z, \mu^2) \left. \right], \end{aligned} \quad (2)$$

with the modified splitting functions defined as

$$\begin{aligned} \tilde{\gamma}_{q \rightarrow qg}(z, x, x_L, \ell_T^2) &= \gamma_{q \rightarrow qg}(z) \\ &+ \Delta \gamma_{q \rightarrow qg}(z, x, x_L, \ell_T^2) \\ \Delta \gamma_{q \rightarrow qg}(z, x, x_L, \ell_T^2) &= \frac{2\pi\alpha_s C_A}{\ell_T^2 N_c f_q^A(x, \mu_I^2)} \left[\frac{1+z^2}{(1-z)_+} T_{qg}^A(x, x_L) \right. \\ &\left. + \delta(1-z) \Delta T_{qg}^A(x, \mu^2) \right], \end{aligned} \quad (3)$$

where $\gamma_{q \rightarrow qg}(z)$ is the normal splitting functions. We assume in the leading order that the gluon fragmentation function follows the normal QCD evolution equations.

Footnotes and References

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